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ACCESS FLIGHT HARDWARE DESIGN AND DEVELOPMENT

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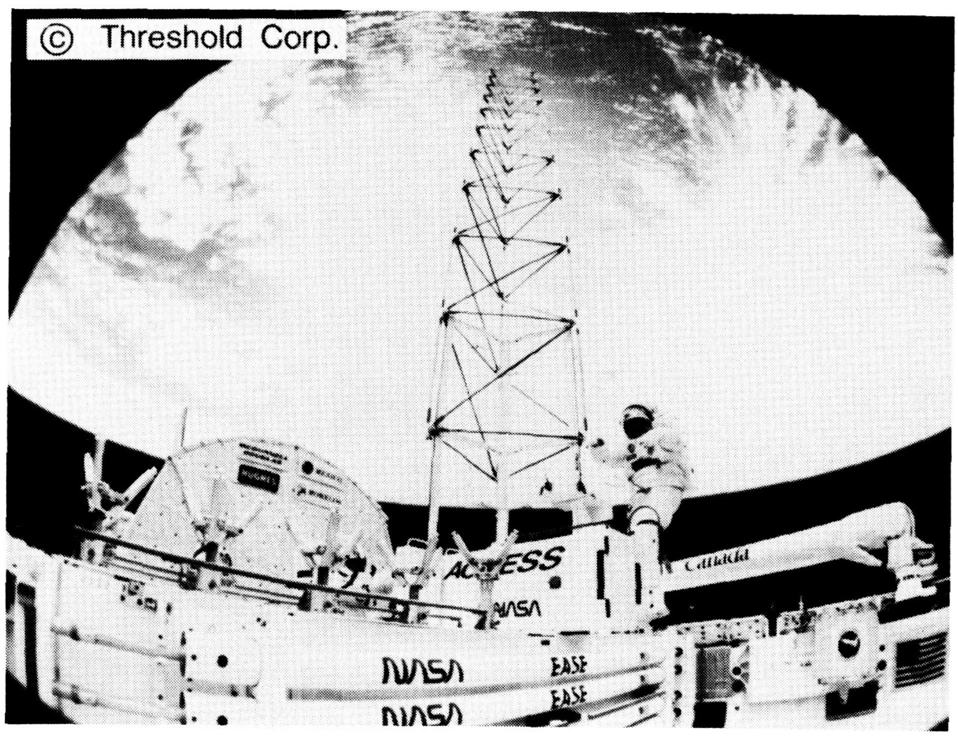
INTRODUCTION

The Assembly Concept for Construction of Erectable Space Structure (ACCESS) Flight Experiment was launched on STS 61B on November 26, 1985. It was the first NASA experiment to study orbital construction of a space truss by astronauts in extra-vehicular activity (EVA). The objectives of the experiment were to: (1) gain on-orbit construction experience, (2) correlate orbital assembly rates and assembly techniques with simulated zero-G ground tests, (3) identify construction procedure elements which will improve erectable structures productivity, reliability, and safety, and (4) evaluate Space Station assembly and maintenance concepts and techniques. In order to meet these objectives, the experiment was composed of two parts. The first part (baseline experiment) was performed during the first EVA period. It consisted of assembling/disassembling a ten bay, 45-foot long truss structure utilizing two astronauts in fixed foot restraints located in the Orbiter payload bay. The second part (expanded experiment) utilized the Remote Manipulator System (RMS) and the Manipulator Foot Restraint (MFR) to provide a mobile work station for an astronaut. This system, including the baseline hardware, was used to evaluate/demonstrate EVA structural assembly, structural repair, flexible utility cable installation, and large structural manipulation during the second EVA period.

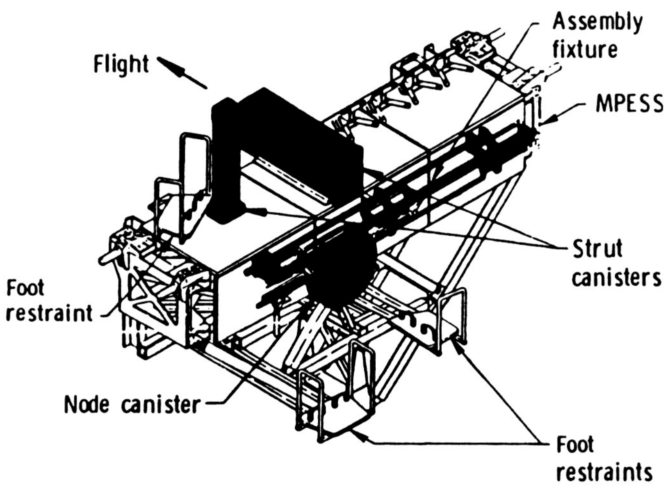


EXPERIMENT HARDWARE DESCRIPTION

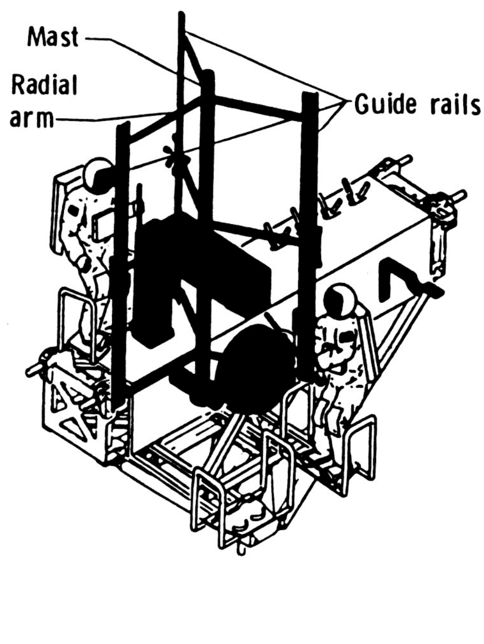
Before describing the hardware, it is important to note some preliminary factors which governed the design of the hardware. The first is that the hardware had to be designed to mount to the Multiple Purpose Experiment Support Structure (MPESS) Pallet utilizing one-half of the top and one side of the Pallet. Within this space, the Experiment had to be stowed, deployed, functioned, and restowed and not interfere with the Experimental Assembly of Structures in EVA (EASE) Experiment. Also the hardware was constrained to be of relatively low cost, completely mechanical, EVA friendly, and capable of being developed in a short time frame.

The ACCESS hardware consists of an assembly fixture, a diagonal strut canister, a batten/longeron strut canister, a node canister, and the truss structure components which are stowed in these canisters. The assembly fixture is rotated from the stowed position to the vertical position (STS Z-axis) and then the guide rails are unfolded to place the assembly fixture in the deployed configuration. The latches on the strut canister doors are disengaged and the doors are rotated to the open position. The spring loaded pin and the backup quick-release pin are retracted on the node canister and the node canister is rotated to an open position. At this point the nodes and struts are removed from the canisters and installed on the assembly fixture to form the truss structure.

ACCESS EXPERIMENT IN STOWED CONFIGURATION

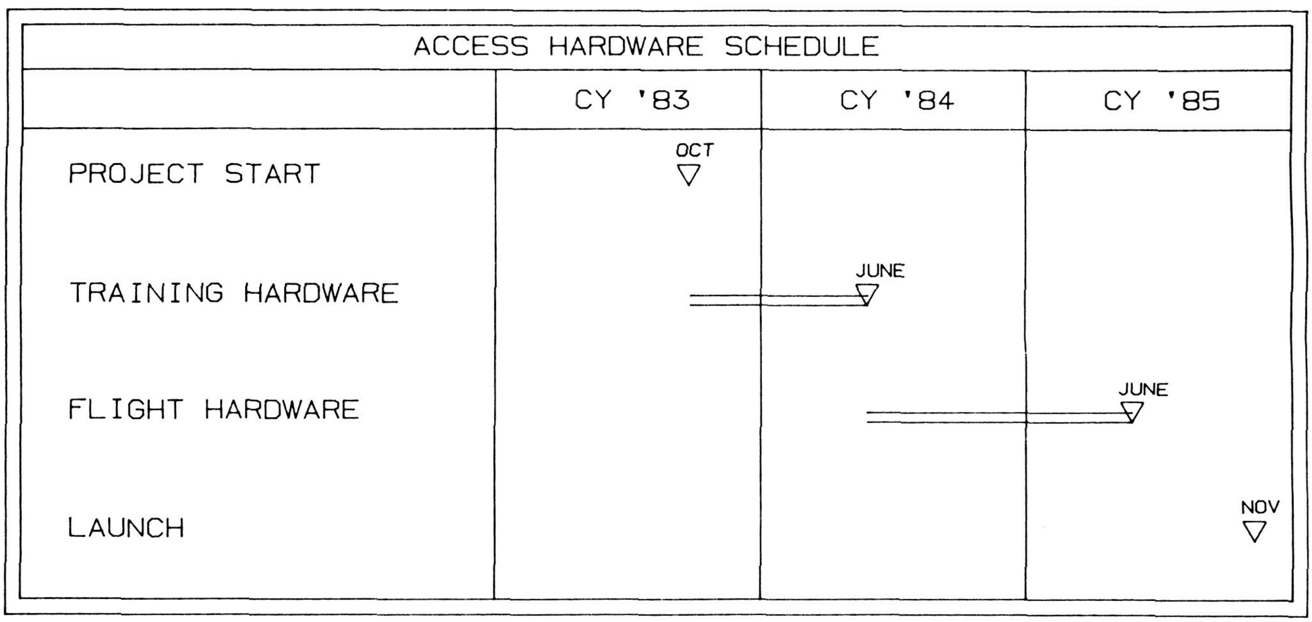


DEPLOYED ASSEMBLY FIXTURE



DESIGN REQUIREMENTS - SCHEDULE

The ACCESS experiment was a payload of opportunity and as such was developed on an accelerated schedule in order to maximize the opportunities for flight. Two sets of hardware were fabricated; the training hardware was delivered eight months after the project's starting date with the flight hardware following twelve months later. Developing the hardware on such an ambitious schedule created immense pressure on all aspects of the project including the design, analyses, fabrication, procurement, testing, and integration.



DESIGN REQUIREMENTS - LOADS

Design loads were developed for the experiment stowed configuration utilizing the STS induced environments. The random load factor (RLF) for in-plane loads was defined to be equal to three times the input GRMS level. For out-of-plane loads, the RLF was determined from the following relationship: $RLF = 3\,[\pi/2 \cdot Q \cdot Fn \cdot PSD]^{1/2}$ where Q equals the component amplification factor, Fn equals the component natural frequency, and PSD equals the power spectral density of the input spectrum at Fn. Three load cases were considered which combined the quasi-static load for all three axes plus the random load factor for each axis respectively. The worst case of these loads was used in the design analysis.

DESIGN LOAD FACTORS FOR LAUNCH

AXIS	QUASI-STATIC LOAD FACTOR (G's)	RANDOM LOAD FACTOR (G's)			
		ASS'Y FIX	BATT./LONG. CANISTER	DIAGONAL CANISTER	NODE CANISTER
X	4.8	3.2	11.9	11.9	16.9
Y	2.7	11.9	11.9	11.9	17.0
Z	5.9	3.2	15.3	16.0	17.0

DESIGN LOAD FACTORS FOR LANDING

AXIS	QUASI-STATIC LOAD FACTOR (G's)
X	6.6
Y	3.0
Z	8.0

DESIGN REQUIREMENTS - STRUCTURAL/DYNAMIC ANALYSES

Finite element models of both the experiment stowed and deployed configurations were developed. These models were integrated into STS system models and used to determine coupled loads and frequency response data when subjected to the STS lift-off/landing and on-orbit environments. These data were used to verify the following structural requirements:

Factor of safety (yield) = 1.25
Factor of safety (ultimate) = 2.0
Component stowed configuration Fn >35 Hz
Experiment deployed configuration Fn > .3 Hz

All of these requirements were satisfied with the exception of the assembly fixture which had a first mode frequency of 32 Hz in the Z-axis. This required that a finite element model of the assembly fixture be generated and integrated into a model of the Multiple Purpose Experiment Support Structure (MPESS). This systems model was used to determine the degree of coupling between these structures when subjected to the simulated STS lift-off and landing environments. These new loads were found to be within the design limits of the hardware.

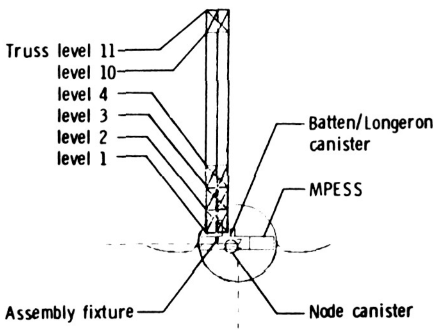
ANALYSIS RESULTS

STOWED CONFIGURATION	FN (HZ)	FACTOR OF SAFETY
DIAGONAL STRUT CANISTER	100	2.06
BATTEN/LONGERON CANISTER	110	2.02
NODE CANISTER	70	2.74
ASSEMBLY FIXTURE	32	2.12
DEPLOYED CONFIGURATION		
TRUSS STRUCTURE-ASSEMBLY FIXTURE	.569	4.08

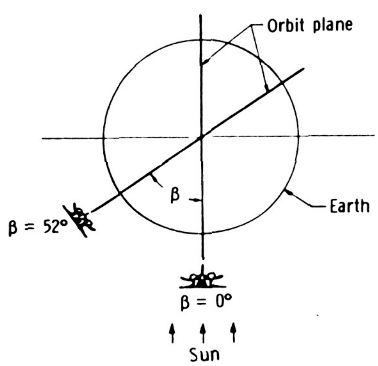
DESIGN REQUIREMENTS - ENVIRONMENT

The experiment hardware had to be capable of functioning in a hard vacuum and within prescribed temperature limits. The temperature limits were developed from the materials capability, the extravehicular mobility unit (EMU) glove interface limits (235°F to -180°F) ref. 1, and the allowable thermal gradients between the individual truss components and between the truss structure and the assembly fixture (ref. 2).

ACCESS THERMAL MODEL



ORBIT ANGLE DEFINITION



ANALYSIS RESULTS

(Bay-to-Earth Attitude)

	Temperatures, °F					
	β = 0°		β = 52°		β = 80°	
	Max	Min	Max	Min	Max	Min
MPESS	+2	−11	−2	−13	+4	−12
Batten/Longeron canister	+3	−24	−1	−21	+25	−2
Diagonal canister	+1	−21	+12	−9	+7	+24
Node canister	+1	−2	−4	−5	−7	−7
Mast	−7	−15	+5	+1	+19	+19
Assembly fixture	−6	−20	+6	−12	+40	+4
Truss (initial)	−11	−11	−8	−8	+14	+14

DESIGN REQUIREMENTS - MATERIALS

Metallic materials were screened to insure compliance with the stress corrosion cracking criteria as specified in reference 3.

Non-metallic materials were screened to insure compliance with the outgassing criteria as specified in reference 4 and 5.

MATERIALS

ASSEMBLY FIXTURE

6061-T6 AL
A286 ss
347 ss
RULON LD
300- SERIES ss
PH 15-7 ss
COHRLASTIC - R10470
(SILICONE RUBBER)
RTV 511
RTV 560
SYNERGISTIC COATING
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT

BATTEN-LONGERON CANISTER

6061-T6 AL
300-SERIES ss
COHRLASTIC-R10470
(SILICONE RUBBER)
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT
RTV 560

DIAGONAL CANISTER

6061-T6 AL
300-SERIES ss
COHRLASTIC-R10470
(SILICONE RUBBER)
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT
RTV 560

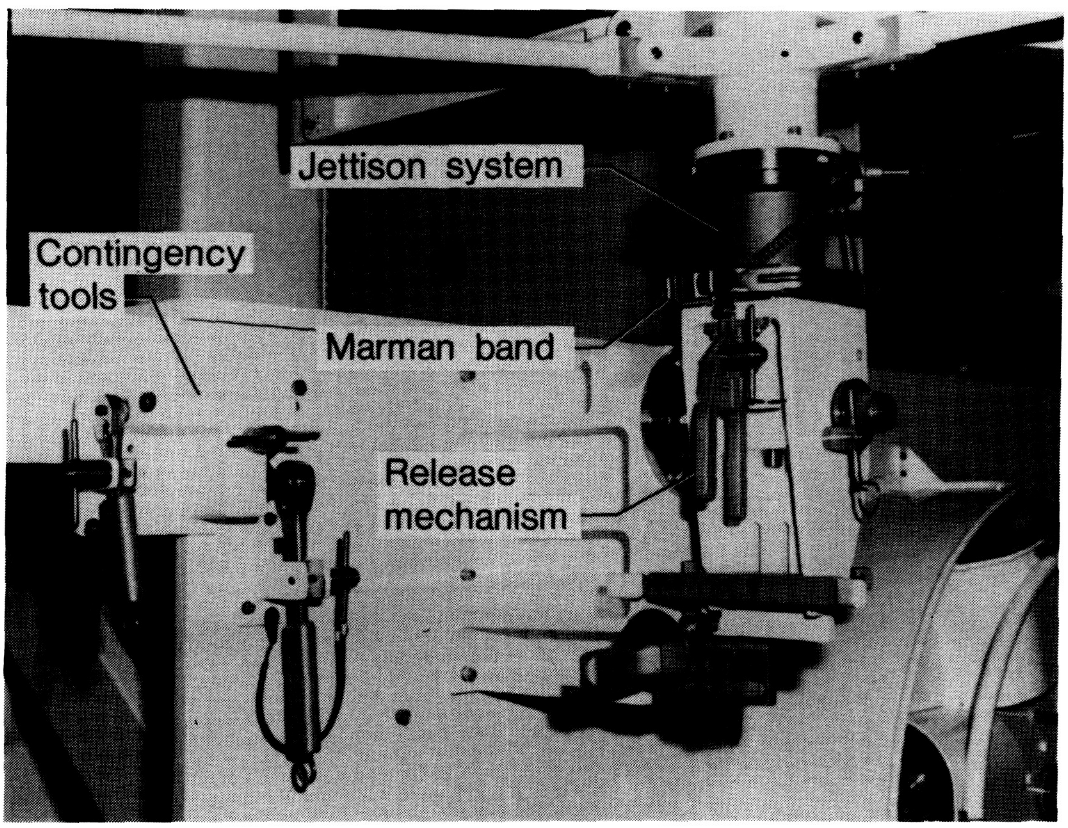
NODE CANISTER

6061-T6 AL
A286 ss
347 ss
RULON A
6061-T651 AL
TEFLON
CHEM GLAZE #9924 PRIMER
A276 CHEM GLAZE WHITE PAINT

TRUSS HARDWARE

6061-T6 AL
300-SERIES ss
7075-T73 AL
KAPTON
SYNERGISTIC COATING

Since the experiment violated the payload bay door envelope when erected, the hazard of being unable to close the doors had to be controlled by independent primary and backup methods, and this combination had to be two failure tolerant (ref. 6). The primary method of controlling the hazard was to disassemble the truss structure and restow the assembly fixture. The backup method involved jettisioning the hardware. This was accomplished through the manual release of an over-center latch on a marman band, retracting two quick-release pins, and squeezing a release mechanism which retracted a third pin. This allowed all of the hardware above the marman band interface to separate from the support structure. In order to provide redundancy in the jettison system, a second over-center latch was provided on the marman band. Also, the hardware could be jettisoned by using the contingency tools to remove four bolts and one nut and manually removing the assembly fixture from its support base.



DESIGN REQUIREMENTS - EVA COMPATIBILITY

The hardware was designed to interface safely and efficiently with the EVA crewmen. To insure that all of the requirements were identified and properly included in the design, reference 1, 7, and 8 were used along with actively involving the crew systems/astronaut personnel in the design, functional testing, and design review process.

EVA COMPATIBILITY REQUIREMENTS

- o SHARP EDGE RESTRICTIONS (.04 MIN. RAD.)
- o TOUCH TEMPERATURE LIMITATIONS
- o CREW INPUT FORCES $\leq$ 25 LBS.
- o AVOID HIGHLY REFLECTIVE SURFACES (SUN GLARE)
- o LIMIT CREW HAND INTENSIVE FUNCTIONS
- o MINIMIZE GLOVE WEAR

DESIGN REQUIREMENTS - FACTURE CONTROL

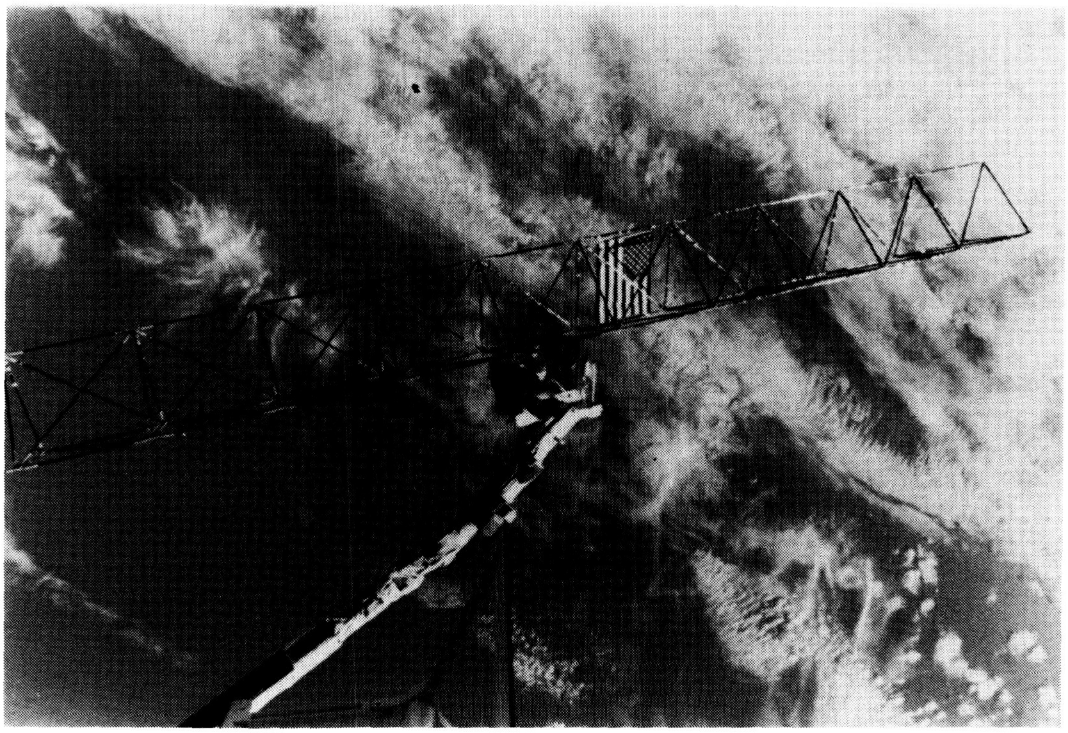
The fracture control requirements were satisfied by designing to the fail safe or safe life criteria as specified in reference 10. The fail safe criteria includes all parts which could completely fracture and not cause loss of life or loss of the Orbiter. Parts which can be classified as fail safe must satisfy one of the three following criteria. The first is that adequate multiple load paths exist which means that after the part has failed the loads can be redistributed through the remaining members with positive margins of safety. The second criteria is that if the part fails it would be contained. The third criteria requires that the part has a mass of .03 lbs or less. The safe life criteria requires that the part has the flaw growth capability to withstand four times the mission life without failure.

ANALYSIS RESULTS

COMPONENT	FRACTURE LIFE (CYCLES)	FACTOR OF SAFETY	A	2C
DIAGONAL STRUT CANISTER	265,000	5.7	.075	.150
BATTEN/LONGERON CANISTER	200,000	4.6	.075	.150
NODE CANISTER	310,000	6.1	.075	.150
ASSEMBLY FIXTURE	150,00	6.3	.075	.150

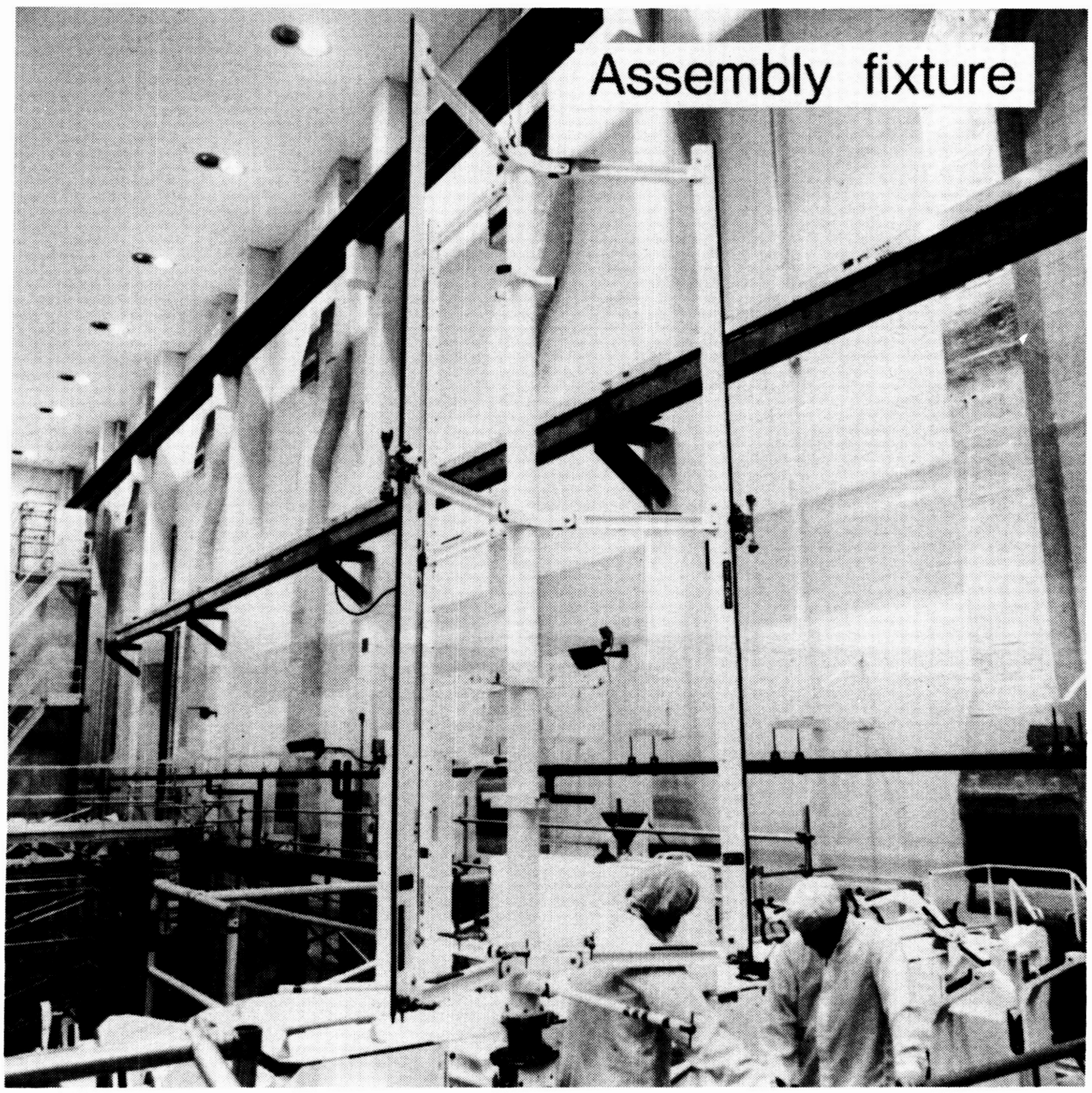
HARDWARE DESCRIPTION - TRUSS STRUCTURE

The truss hardware consists of 33 battens (horizontal strut members), 30 longerons (vertical strut members), 30 diagonal struts, and 33 nodes. The struts are fabricated from 1.0-inch diameter by .058-inch wall thickness 6061-T6 aluminum tubing and are insulated with .001-inch thick Kapton aluminized on one side. The batten and longeron struts are 3.95 feet long and the diagonal struts are 5.81 ft. long. The struts have quick-disconnect joints attached at each end to provide for easy attachment and removal of the strut to the node. The node consist of five parts fabricated from 7075-T73 aluminum. The guide part of the node slides on a 0.500-inch dia. stainless steel rod attached to the end of the guide rails on the assembly fixture. The guides as well as the stainless steel rods are coated with a synergistic coating process in order to minimize the frictional forces developed when the truss structure slides on the assembly fixture. These components are stowed in canisters for containment during the lift-off and landing phases of the flight and are individually removed on-orbit for assembly of the truss structure.



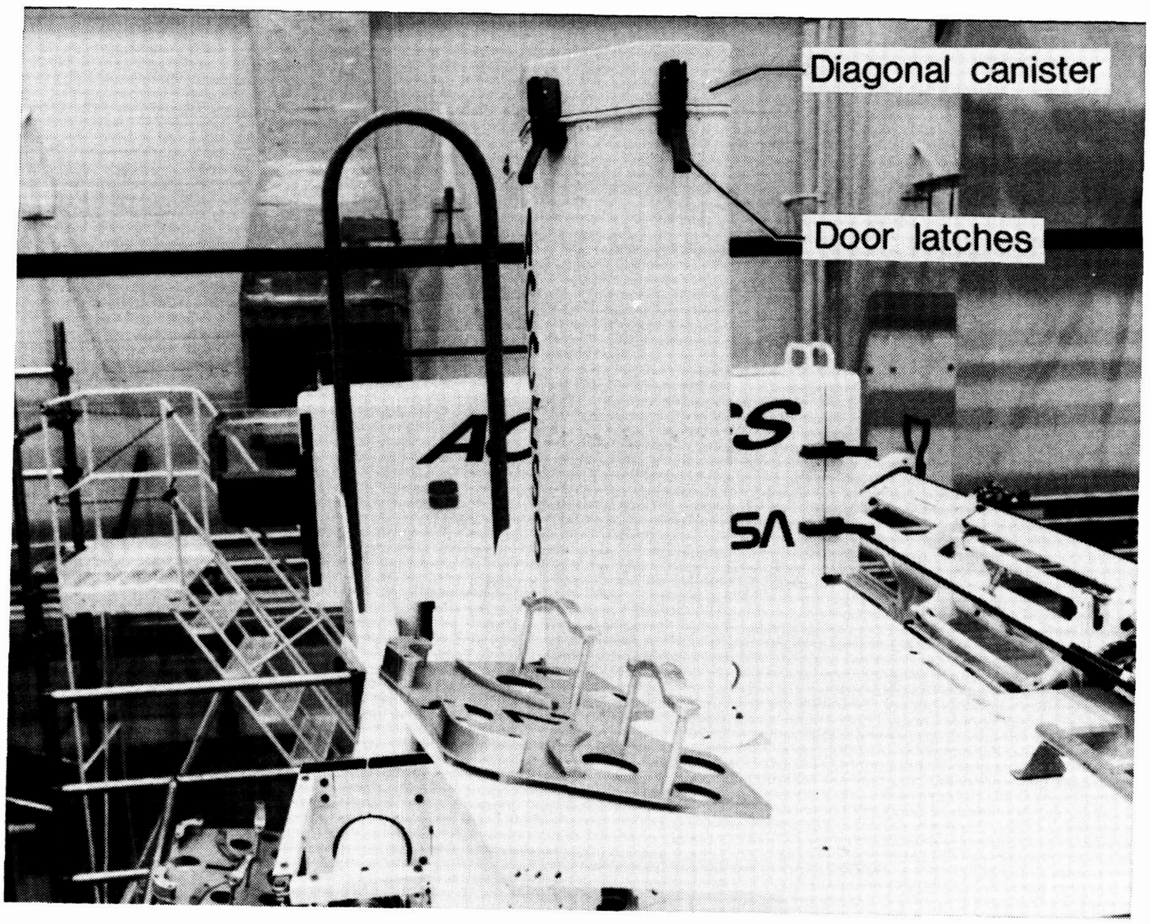
HARDWARE DESCRIPTION - ASSEMBLY FIXTURE

The assembly fixture consists of a 4.0-inch diameter aluminum core tube with three guide rail assemblies which are stowed next to the core tube for lift-off and landing. The core tube and guide rails are attached to the MPESS pallet through a bracket at the base of the core tube and two mast clamps. Once in orbit, the mast clamps are manually opened and the assembly fixture is rotated to the vertical position (STS Z-axis) and the guide rail assemblies are deployed. This system rotates about the centerline of the core tube providing a moving structure on which to assemble the truss structure. The assembly fixture is two bays long providing room for the assembly of one bay and structural support for the bay of truss structure immediately above the assembly area.



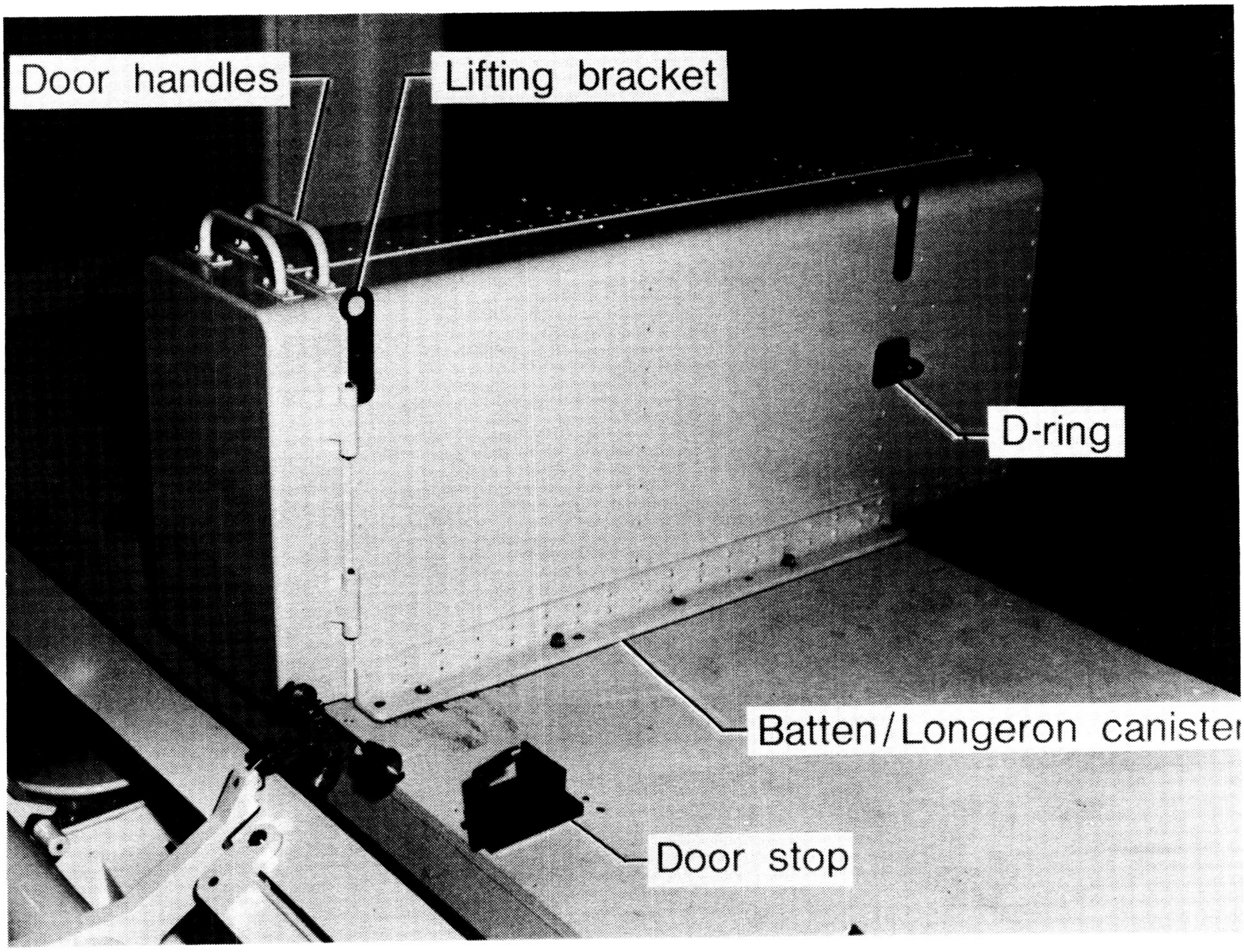
HARDWARE DESCRIPTION - DIAGONAL CANISTER

The diagonal strut canister is an irregular shaped 6.0-ft. long canister which houses 3 battens and 30 diagonal struts. The canister is mounted on the top surface of the MPESS pallet with 2.6 ft. protruding through the top surface into the inside of the pallet geometry. The canisters consist of 5 baffle plates, 33 thin-wall aluminum guides tubes running the entire length of the canister, a 0.06-inch thick aluminum skin forming the exterior surface, and a door with redundant latches to contain the struts. The struts are stowed in the canister with a 1.5-inch stagger between rows to allow for unaided removal of the struts from the canister by the space suited astronaut. Spring clips are installed in each guide tube to prevent the struts from accidentally floating out of the canister once the door is opened.

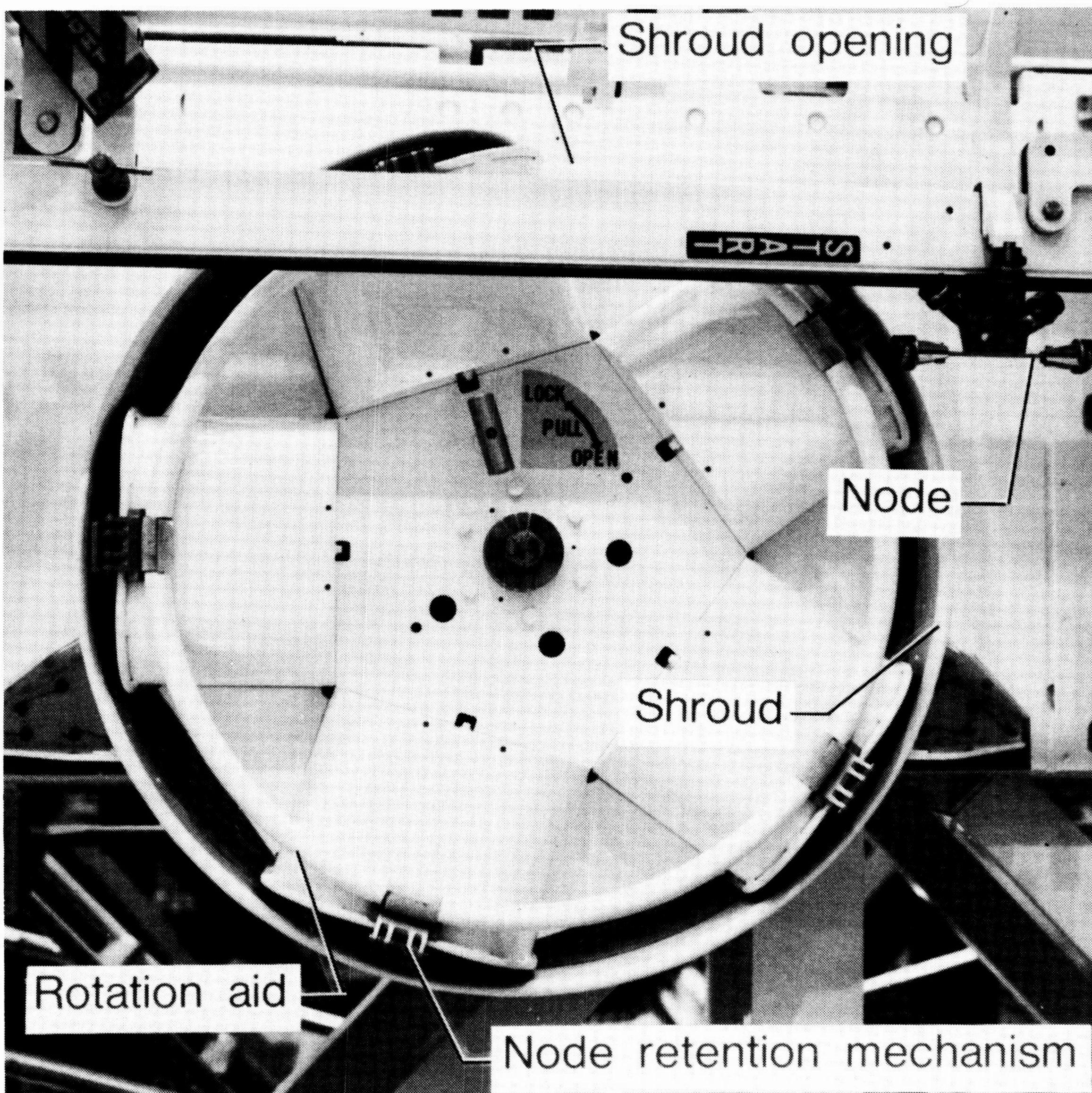


HARDWARE DESCRIPTION-BATTEN/LONGERON STRUT CANISTER

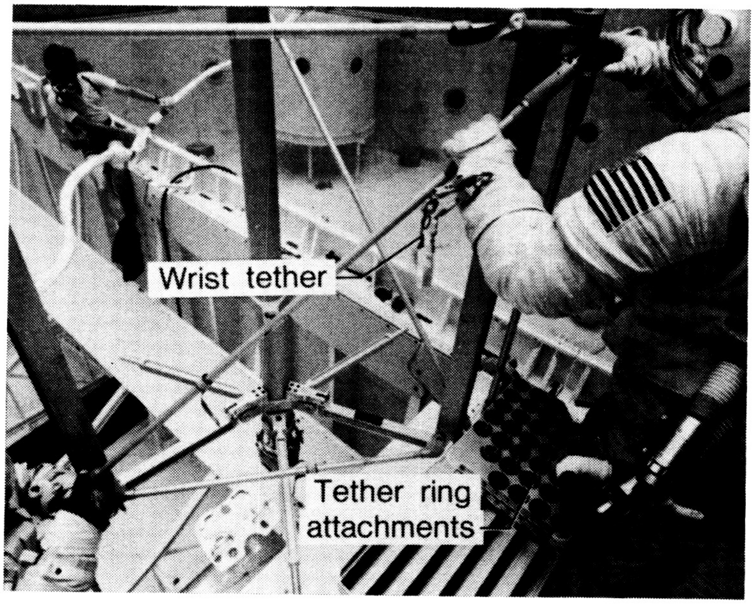
The batten/longeron canister is 1.0 by 1.5 by 4.1 feet long and houses 60 batten/longeron struts. It is mounted on the top surface of the MPESS pallet facing aft in the STS cargo bay. The batten/longeron canister design is identical in concept to that of the diagonal canister. The "D" ring brackets are mounted on both sides of the canister to provide an attachment point for the payload retention device (PRD). The PRD would be used to hold the door closed for reentry in case the canister latches failed on-orbit. The door stop bracket is used to hold the door open during the removal and stowage of the struts.

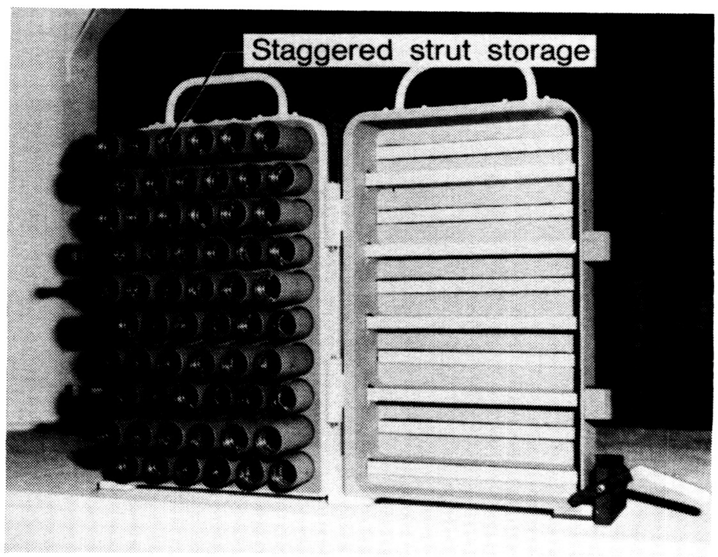


The node canister is circular in shape and rotates about a central shaft. It is locked into its launch/landing orientation by a spring loaded pin and backup quick release pin. It is composed of five separate compartments, each housing six nodes with the remaining three nodes stowed at the midpoint of each guide rail on the assembly fixture. This system is manually rotated inside a shroud with an opening large enough to remove the nodes from one compartment at a time. The nodes are retained in the individual compartments by node retention mechanisms which rotate inside the shroud and can be pivoted out of the way at the shroud opening for removal and stowage of the nodes.

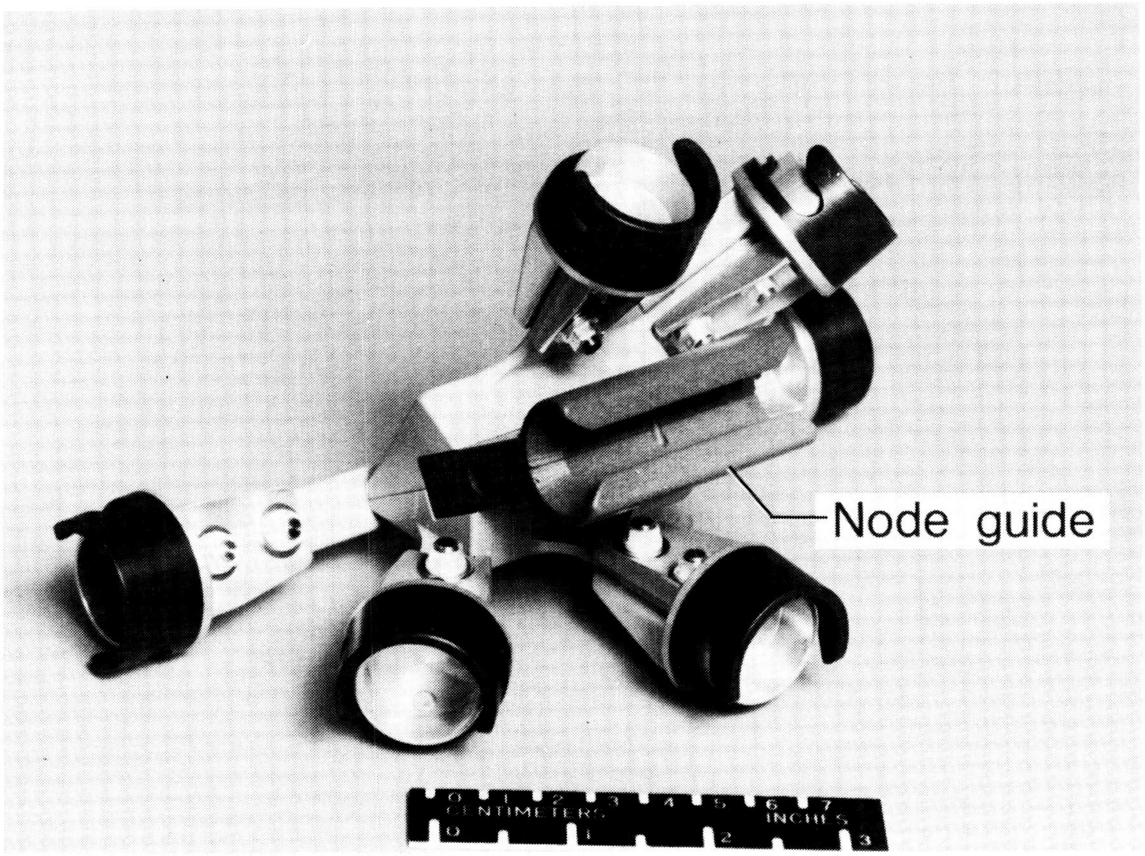


There was an original requirement to tether each node and strut prior to being removed from its stowage canister and remain tethered until the component had been securely integrated into the structure. Through testing, this proved to be a very cumbersome, time consuming, and hand intensive process; and with the support of the astronauts this requirement was waived. This allowed the tether ring attachments to be removed from the struts which required that another means be provided for removing the struts from the canisters. The resulting design provided for staggered stowage of struts in the canister which allowed for relatively easy removal and replacement of the struts. The node canister design had always required that the nodes be removed from the canister directly by the astronaut. Therefore the waiver of the tether requirement necessitated no design changes to the nodes or the node canister.



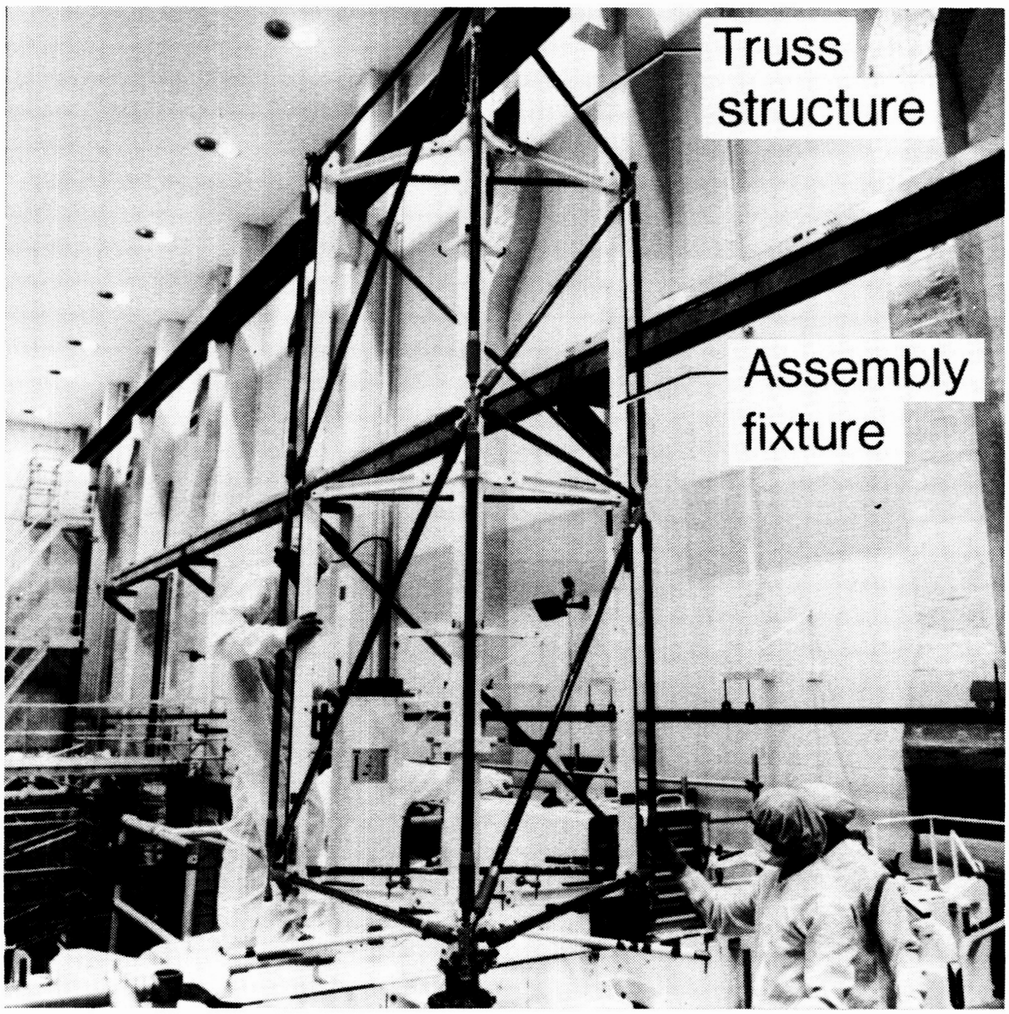


With so many metallic surfaces rotating, sliding, and interfacing directly in close tolerance joints, proper coatings to minimize friction and increase the wear characteristics of these materials were of immediate concern. Although these problems surfaced in all the major components, the primary area of concern was with the truss structure sliding on the assembly fixture. The particular pieces of hardware involved in this operation were the truss structure node guides manufactured from 7075-T73 aluminum which slid on the 0.500-inch diameter stainless steel rods attached to the ends of the guide rails on the assembly fixture. A synergistic coating process was chosen for each of these items and proved to be reasonably effective in preventing galling and allowing the hardware to function as designed.



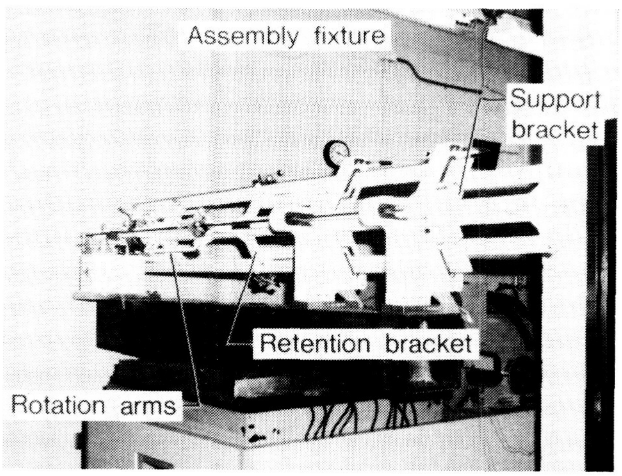
DEVELOPMENT PROBLEMS AND SOLUTIONS - TRUSS ASSEMBLY

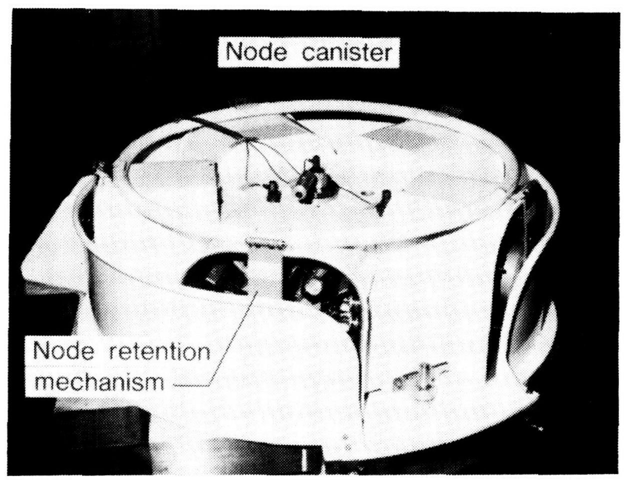
In order for the truss structure to exhibit reasonable structural characteristics, it was necessary to minimize the tolerance in the joint between the strut and node. For the ACCESS flight hardware, this tolerance was 0.001-inches which did not allow adequately for tolerance buildup in the manufacturing and assembly of the hardware or for the expected on-orbit thermal gradients. This concern was addressed by controlling the tolerance buildup of the individual parts and proper fixturing for the assemblies. The thermal gradients were minimized by selecting specific coatings and insulation material for the assembly fixture and truss structure. The entire system was then made more tolerant of the changes in the geometry of the structure by adding flexible bushings to the assembly fixture. This approach was verified by physically varying the lengths of the struts while mounted on the assembly fixture to determine the maximum allowable changes in lengths of the struts. These changes in length of the struts corresponded directly to thermal gradients between the truss structure and the assembly fixture which were predicted by a very detailed thermal model.



DEVELOPMENT PROBLEMS AND SOLUTIONS - VIBRATION TESTING

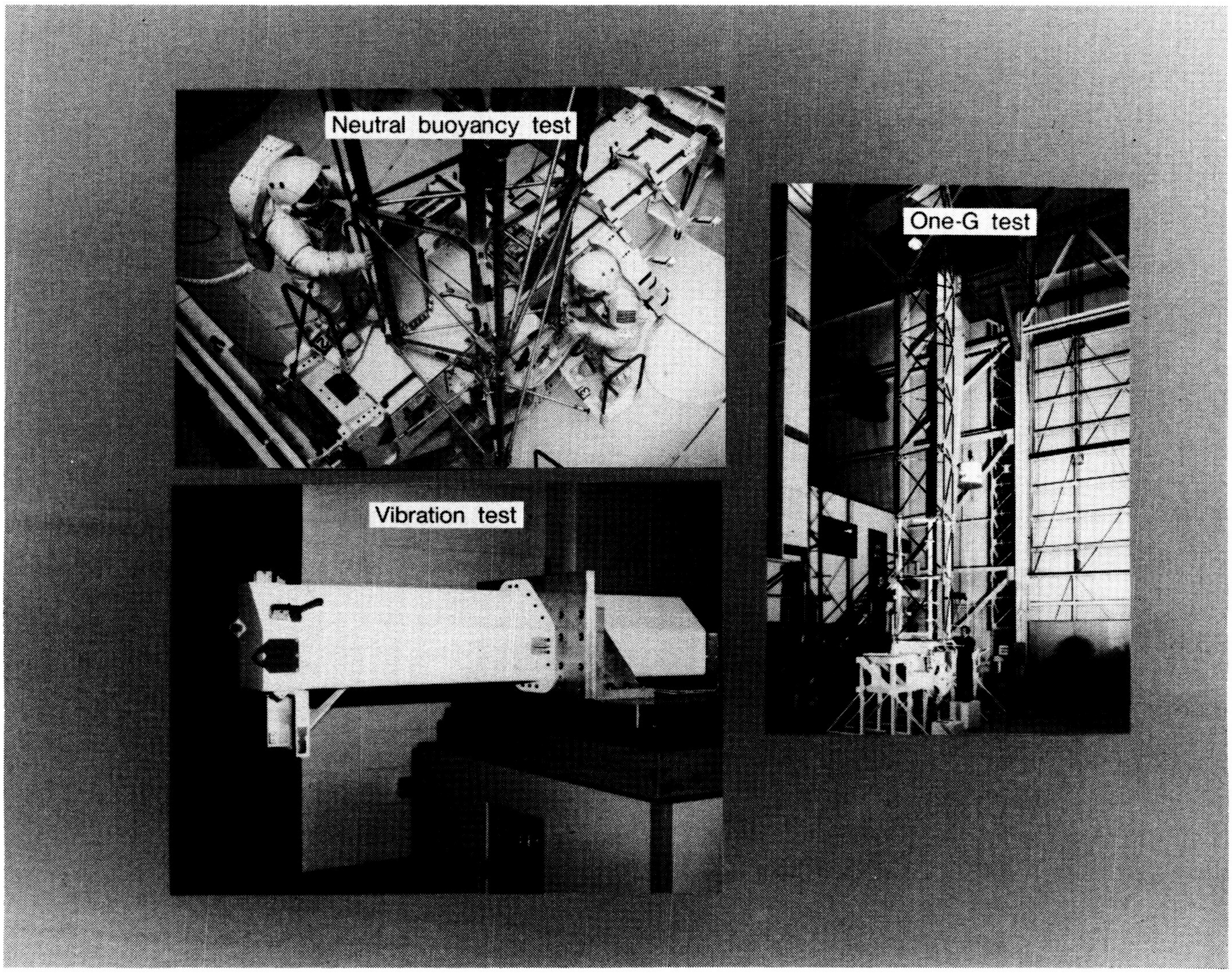
A number of problems were encountered during the vibration testing of the training hardware, in particular with the assembly fixture and the node canister. The assembly fixture required that two vertical rail retention brackets be added, the rotation arms and stowage brackets be modified, and that a radial arm support bracket be added in order for the assembly fixture to pass the vibration tests. Even with these extensive modifications the first mode frequency for the Z-axis was 32 hz which was 3 hz less than the design requirement and required specific attention during the coupled loads analyses. The node canister required that a node retention mechanism be added to each node stowage compartment in order to retain the nodes securely in place during vibration testing.





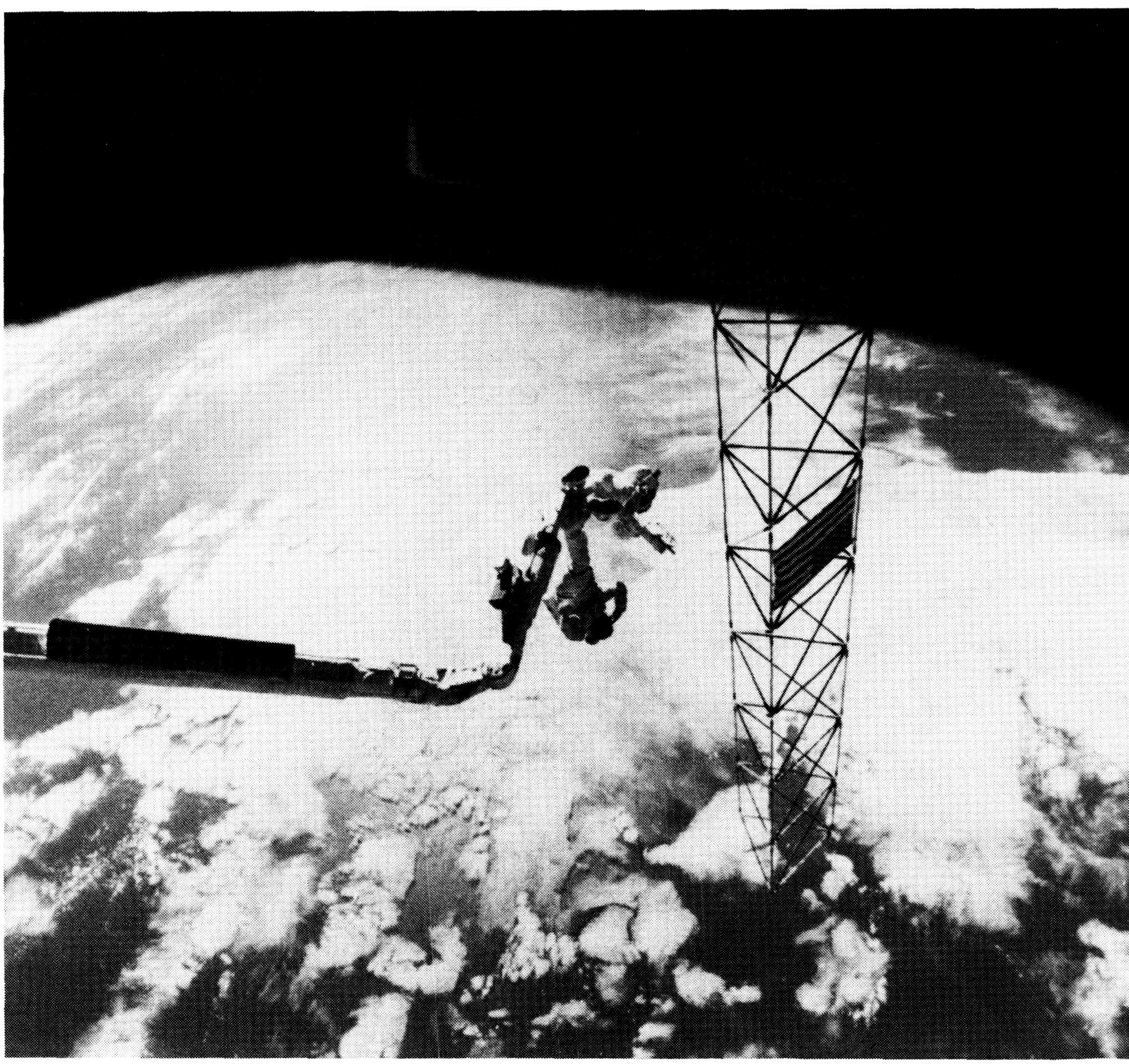
TESTING

Various functional and environmental tests were conducted on both the ACCESS training and flight hardware. The training hardware was subjected to extensive simulated zero-G tests at the Marshall Space Flight Center's Neutral Buoyancy Simulator and the Weightless Environmental Test Facility (WETF) at the Johnson Space Center. These tests were used to verify that the hardware functioned as designed, to develop assembly procedures and timelines, and to train the astronauts prior to flight. One-G tests were conducted on the training and flight hardware to develop procedures and to verify that the hardware functioned properly. Both sets of hardware were subjected to a series of vibration tests which simulated the STS lift-off and landing environments. These tests were used to determine the first mode frequencies, amplification factors, and to insure survivability of the individual components. A series of thermal tests was conducted on the training hardware to insure proper functioning of the hardware and to verify specific inputs to the thermal model.



CONCLUSIONS

Several items were found to be of immense value in the design and development of the ACCESS hardware. The early availability of mock-up and engineering test hardware helped to develop the concept and prove the feasibility of the experiment. The extensive neutral buoyancy testing was invaluable in developing the procedures and timelines, proving that the hardware functioned as intended, and effectively training the astronauts. The early involvement of the crew systems/astronaut personnel was extremely beneficial in shaping the design to meet the EVA compatibility requirements. Also, the early definition of coupled loads and on-orbit dynamic responses can not be overemphasized due to the relative uncertainty in the magnitude of these loads and their impact on the design.



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